Production Improvement Plans for Dimension Stone Quarrying:
A Case Study of Granite Mine of Kyber Pakhtunkhwa Province of Pakistan

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Abstract: Utilization of mechanized methods of dimension stone quarrying has caused an accelerated revenue generation and hence increased profit margin. Bench cutting through diamond wire saws are one of such mechanized method. In Pakistan, this technique is being used by few companies one of the pioneers of which is M/s Indus Mining (private) limited-IML. One of its operational quarries is of black mamba granite. Inspite of fairly large quantity of compatible machinery and technically skilled labor, it had been unable to produce a profit generating production. A set of plans were proposed which require the duration ranging from one week to five months for their implementation. These plans comprised of technical change in benching, optimum utilization of workers and machinery, workers’ morale boosting and origination of a new level for production. When these plans had been implemented the mine observed a remarkable increase in the production.

Key words: Dimension stone quarrying • Granite Mine • Pakistan

INTRODUCTION

Dimension stone is generally defined as natural rock quarried for the purpose of cutting and (or) shaping to a specific size with or without one or more mechanically furnished surfaces for structural or decorative purposes in construction and monumental applications [1-5]. The ultimate success in marketing a natural stone as a dimension stone lies firstly in its appearance and secondly in the possibility of producing rectangular blocks of suitable dimensions [6]. Another important selection criterion is durability, the time measure of the ability of dimension stone to endure and to maintain its essential and distinctive characteristics of strength, resistance to decay and appearance [7]. Granite, marble, onyx, quartzite etc fall into the category of dimension stones.

Commercially, the term ‘granite’ includes a range of other types of non-granite dimension stone including any feldspathic crystalline rocks or other igneous or metamorphic rocks which possess qualities similar to granite’s grainy, interlocking texture. Many variations of granite appear on the commercial market with white, gray, pink and red being the most common primary colors. Greens and browns are also available as well as darker grays and black [8].

Due to the desire for increased profits and pressure from the international markets, the mining industry explored cheaper and faster methods for mineral extraction [9, 10]. Deep surface mining was slowly phased out and by the early 1990’s was completely taken out of production. Surface mining became the ideal method for exploitation [11]. Extraction (more commonly referred to as quarrying) consists of removing blocks or pieces of stone from an identified and unearthed geologic deposit. Differences in the particular quarrying techniques used often stems from variations in the physical properties of the deposit itself-such as density, fracturing/bedding planes and depth-financial considerations and the site owner’s preference.
Table 1: Coordinates of the lease area of black (and Grey) granite owned by M/s Indus Mining (pvt) Limited.

<table>
<thead>
<tr>
<th>Point</th>
<th>Easting</th>
<th>Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1,143,050</td>
<td>3,193,999</td>
</tr>
<tr>
<td>B</td>
<td>1,143,050</td>
<td>3,195,828</td>
</tr>
<tr>
<td>C</td>
<td>1,142,108</td>
<td>3,195,828</td>
</tr>
<tr>
<td>D</td>
<td>1,142,108</td>
<td>3,193,999</td>
</tr>
</tbody>
</table>

Different techniques have been used for quarrying dimension stones one of which is the mechanized technique of diamond wire sawing. In this technique of quarrying, bench is drilled with three mutually perpendicular holes with only one point of junction. The bench is then cut in three mutually perpendicular planes to make it free from the rest of the rock. Once the bench is cut in all three planes, it is dropped by means of hydro bag and/or hydraulic jack. Squared blocks are produced through cutting with wire saw or line drilling.

**AAA Mine of Black Granite-A Project of M/s Indus Mining (Private) Limited Pakistan:** M/s Indus Mining (pvt) Limited has been dealing in dimension stone quarrying in Pakistan for the last five years. One of the successfully operated quarries owned by this company is of Black Granite situated in village Jiggi, tehsil Oghi and district Mansehra. The deposit is a part of Susal Gali formation. On the same deposit, there exist nearly ten small scale mines in the radius of 6 km approximately. The lease area consists of 402 acres containing black granite and grey granite. The coordinates of lease area are given in table 1.

The longitude of the deposit ranges from 72°54'30" E to 72°55'40" E approximately while latitude ranges from 34°26'10"N to 34°26'35" N approximately as shown in figure 1.

Black granite has been worked out by this company in two phases namely AAA and AAA-Upper Deposit both of which are small scale mines. Figure 2 describes working levels and other features of AAA mine. This mine has a longitudinal span of 120 m, lateral span of 20 m, total height of (existing two) benches is currently 18 m. If two more benches are produced a further workable height of 20 m will be obtained. At this point the deposit will have a potential safety and stability problem.

Major cracks are oriented in the deposit at an angle of 20° from north as shown in figure 3.

The quarry has been developed in a way that the benches are positioned with their long face at an angle of 20° from north (Figure 3). Bench height is 9 m on average, width is 8 m and thickness is approximately 2.0 m. This mine has a remaining life of approximately 5 years with an average excavation of 1,200 cbm per month. Currently two levels are active which are named as level one and level zero. Two further levels are planned to be opened in future. Level one has a very low recovery of less than 5% because of the presence of cracks and giant white spots. Level zero has a fairly high recovery of as much as 50% with a probability of presence of export quality material.

Overall condition of the deposit is such that during last year, approximately 75% of the total monthly production lies in the category of local blocks.

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![Fig. 1: Geographical map of black granite deposit leased by M/s Indus Mining (pvt) Limited.](image-url)
Four quality-based categories of blocks are produced from this mine. These are export quality, local quality, fractured and white spots. Based on the dimensions of block, export and local qualities have been further classified into class one and two.

The company has employed 61 technical workers including a site manager, two qualified and experienced engineers along with two quarry masters for quarry works performed in two shifts of eight hours each. The team in each of the two shifts comprises of an engineer, a quarry master, a skilled supervisor, DTH drill machine and wire saw operators (for three DTH machines, four wire saws of main motor of 50hP, four spherical machines and two jack hammers) with a helper for each of DTH and wire saw machines. The operators of all machineries other than excavators could operate every machine. Two excavator operators along with a helper for each machine are also present during a shift. During the day shift, loading staff is also present which include two crane operator and four loading assistants. The reason behind this high number of workers is cheap labor and the need of manually performed tasks because of the unavailability of more modern techniques of dimension stone quarrying. Bench drilling is done with Down the Hole (DTH) drill machine, cutting is done with diamond wire saw and block squaring is done with spherical and/or diamond wire saw and/or jack hammer. Diamond wire cutting machines are indispensable machines, which are used in natural stone
quarries at various stages ranging from block production to the final good. Today, they are widely used in more than 90 % of the natural stone quarries [12]. These diamond wire saws are employed in such a variety of circumstances because of their high flexibility, high production rate, low noise level, low cost and high energy efficiency, particularly when compared to circular saws [13].

With the quantity of machinery utilized and infrastructure developed at site, the revenue generated as a result of production was merely supposed to equalize the expenses. The production optimization plans were proposed and implemented for AAA mine which resulted in the increase of production by 45 % approximately.

**Problem Statement:** Inspite of sufficient quantity of machinery and skilled laborer, the mine was unable to produce such sufficient volume of blocks as to meet market demands. In addition, the production was not even sufficient to achieve monthly break even. The problem was to optimize the production by considering following parameters:

- The production should be too sufficient to make the project profitable on both monthly and overall basis.
- The quantity of fuel required to produce unit volume of block should either decrease or remain same as previous.
- Increase in production should never mean to be a compromise on the maintenance and/or repairing of machinery (i.e. providing no free time for a machine for maintenance e.g. greasing etc).
- Increase in production should never mean to decrease the productivity of the staff (i.e. to hire more workers).
- The improvement in production should be consistent and not just the once stunt.
- The production should not be frozen but it should be consistently dispatched to the ware house (sale point of blocks) as none of the blocks is sold from mine.
- The laborers should not be given more tough time than the normal as it will not only increase expenses (in the form of over time remuneration) but also decrease the useful life and psychological disturbance to the worker.

**Proposed Remedial Plans:** The remedial plans proposed to overcome this set of problem were not one-dimensional. Some of the plans were proposed for immediate implementation while others were proposed to be completely implemented within three months of the proposal date. Following were the proposed plans:

- **Change the Existing Quarrying Plan (Increase the Thickness of Benches by One Meter):** This plan had been implemented immediately.
- **Start of an Additional Shift with Already Available Staff.** This plan had been implemented immediately.
- **Morale Boosting for All Workers.** This plan had been implemented immediately.
- **Origination of a New Level.** This plan requires five months for its complete implementation.

Following is the detail description of all of these plans.

**Change the Existing Quarrying Plan (Increase the Thickness of Benches by One Meter):** The deposit contains green lines, white lines, fractures and white spots as unwanted features to be an export quality block, however, all these features are acceptable in the local market provided not present in access. Blocks (and tiles) have been marketed in such a manner that green lines become an attractive pattern for the customers. So, the block, though preferable either to be free from lines or contain green lines along the length, are also attractive for the customers if these contain lines across the length. Similarly, the block, if contains fracture, is favorable if and only if the crack is parallel to the length and it should not be more than one in a block. Each bench contains at least one and at most two major fractures (in the same direction as that of bench dropping) which cause the bench to be dropped in more than one part. Previously, the bench dimensions were 9 m height, 8 m width and 2 m thickness. The blocks can be produced along the height, width as well as along thickness; however, the probability of block along thickness of the bench is very small because of chipping of the bench, edge break when bench is dropped or presence of crack etc. In addition, as mentioned earlier, local category block are classified on the basis of length with more length meaning more salvage value. Therefore the thickness of 2 m is not that much favorable. However, the advantage of this thickness is easy dropping of the pieces of bench (separated by major cracks). Experience has shown that in this mine with such dimensions, any of these pieces has a weight of approximately 200 tons which can be dealt easily with a hydraulic jack of push force capacity for 300 tons bench.
Table 2: Increase in Time Required for Drilling a Complete Bench according to New Plan

<table>
<thead>
<tr>
<th>Dimensions (m)</th>
<th>Previous Practice (9m × 8m × 2m)</th>
<th>New Practice (9m × 8m × 3m)</th>
<th>Increase in Time</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>L.T. 00:25 O.T. 02:15</td>
<td>L.T. 00:25 O.T. 02:15</td>
<td>00:00</td>
<td>0.00</td>
</tr>
<tr>
<td>Width</td>
<td>00:25 02:00</td>
<td>00:25 02:00</td>
<td>00:00</td>
<td>0.00</td>
</tr>
<tr>
<td>Thickness</td>
<td>00:25 00:30</td>
<td>00:25 00:45</td>
<td>00:15</td>
<td>27.27</td>
</tr>
<tr>
<td>Total Time</td>
<td>01:15 04:45</td>
<td>01:15 05:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>06:00</td>
<td>06:15</td>
<td>00:15</td>
<td>4.17</td>
</tr>
</tbody>
</table>

Table 3: Increase in Time Required for Cutting a Complete Bench according to New Plan

<table>
<thead>
<tr>
<th>Dimensions (m²)</th>
<th>Previous Practice (9m × 8m × 2m)</th>
<th>New Practice (9m × 8m × 3m)</th>
<th>Increase in Time</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height × Width</td>
<td>L.T. 00:20 O.T. 14:24</td>
<td>L.T. 00:20 O.T. 14:24</td>
<td>00:00</td>
<td>0.00</td>
</tr>
<tr>
<td>Width × Thickness</td>
<td>00:20 03:12</td>
<td>00:20 04:48</td>
<td>01:36</td>
<td>50.00</td>
</tr>
<tr>
<td>Height × Thickness</td>
<td>00:20 03:36</td>
<td>00:20 05:24</td>
<td>01:48</td>
<td>50.00</td>
</tr>
<tr>
<td>Total Time</td>
<td>01:00 21:12</td>
<td>01:00 24:36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>22:12</td>
<td>25:36</td>
<td>03:24</td>
<td>14.60</td>
</tr>
</tbody>
</table>

In order to optimize production (hence revenue), if the bench thickness is kept as 3 m, the probability of long blocks as well as the recovery from bench will also increase. Bench drilling time would increase by minutes only while there would be no appreciable increase in the bench cutting time. Machine leveling and setting time either for bench drilling, cutting or block squaring would be same for all cases. There would be a small increase in the operating time of machinery, however, the volume of squared block produced as a result of this were much more than this increased operating time. Approximately an additional time of 3.75 hours was observed in bench drilling and cutting while the production increased by 40%.

For the black granite of the mine referred in this mine the penetration rate of DTH hammering rod with button bit is observed to be 4 m per hour. For three dimensions of the bench, change in drilling time is tabulated for previously defined dimensions and amended dimension in table 2. Similarly, at an average cutting speed of 5 sq. m per hour, an increase in the bench cutting time is tabulated for three plans of a bench in table 3. L.T. refers to leveling time required for DTH/ wire saw leveling, while O.T. refers to operating time.

As the drilling required for squaring varies from block to block therefore the time required for it could not be tabulated, however, it has been observed that the bench with dimensions as defined by the previous practices (9m × 8m × 2m) requires nearly 32 work hours (4 shifts of eight hours) for its complete squaring into the regular shaped block of black granite of discussed mine. The time required for processing the benches with new dimensions (9m × 8m × 3m) required nearly 48 work hours for its complete processing into the regular shaped blocks.

The recovery of blocks from level zero in the first case was observed to be nearly 35%. When the bench thickness had been kept 3 m, recovery increased upto 50%. It had also been observed that this change in the previous plan also increased the probability of export quality blocks. With the same volume of blocks as produced previously, the revenue generation through the new plan was much more than the previously observed (because of the increased length of blocks).

Drilling in black granite is more difficult as compared to cutting by diamond wire saw. Initially, the dropped bench had been converted into block by means of spherical and similar drilling machinery. In order to increase the speed of squaring, it was proposed to utilize wire saw along with drilling machinery. As an implementation of plan, wire saw was utilized for squaring edges of large blocks which had been produced from dropped benches. This did not only accelerate squaring but also reduced the noise and dust which had been produced by drilling.

It is also important to consider that experience has revealed that increase in the thickness of bench by one meter created an additional weight of 95 tons approximately in the larger parts of bench.
Hence the piece which had a weight of 200 tons would have weight of 295 tons by the increase of one meter thickness. This could be handled easily with the hydraulic jack plant of push capacity of 300 tons. If we increase the thickness more, the larger pieces could not be pushed by the available hydraulic jack.

**Start of an Additional Shift with Already Available Staff:**
As described earlier that an additional time of approximately 19.75 hours was required to process a bench with 3 m thickness, therefore the solution to this problem might be either to ask the laborer for an additional paid over-time work or to start another shift (even with lesser number of workers compared to the other two shifts). The problem in adopting first solution was that the workers might feel a sense of discomfort and also a tired worker, at the end of a shift, would never produce the same result as the fresh worker at the start of the shift. Therefore, it seemed to be a better option to start another shift of workers by taking some workers from other two shifts.

Rather than doing work in two shifts of eight hours each, it was better to have three shifts of seven hours each. The advantage of this proposal was manifold.

- Productivity increased with the increase of total work hours of site per day.
- Distributing workers in two shifts would increase the probability of assigning a machine to the least possible number of workers. This did not only create a high sense of responsibility to the workers but also improved the maintenance of machinery.
- Reducing the work hours per shift by increasing total number of shifts created a sense of relaxation to the workers.

Following is a comparison of increase in the work hours per day and availability of fresh work hours keeping man hours per day same as per previous practice.

Previously for each shift there were 30 workers including management staff. As a change in plan, total of 61 workers had been divided into three shifts in a manner that the site manager had been reserved for day shift only in both of the new and old plan.

- Each of the two engineers was also deputed only in the morning and evening shift.
- Each of the two quarry masters was deputed in the morning and evening shift only.
- Both of the two supervisors were deputed in the night shift.

- A team of loading staff was divided into two groups with an operator and two assistant in morning and evening shifts each.
- The excavator operators with helpers would work in two shifts of eight hours as per previous practice and, if required, they perform work in additional overtime.
- As described earlier that only two levels have been present out of which only one contributes to nearly 95% of the total production, so, to get maximum output from machinery, only two DTH drill machines, three wire saws, three sphericals and two jack hammers were utilized for active working while the remaining machinery was kept in the warehouse.
- 14 workers were deputed in the morning and evening shifts each.
- In the night shift, 12 workers were deputed.

It is experienced in the field that due to the exposure to extreme weather conditions workers remain more active during the first three hours of each shift, their activeness decline with passing time and during last two hours they start getting tired. Even during the eighth hour, their performance is quite ordinary or below it. If we allocate the staff in three shifts, then eighth hour of the day will be the first hour of the new shift and the workers will be fresh thereby taking participation in the tasks actively. This activeness will remain during the ninth and tenth hour of the day also. Similarly, during the fifteenth, sixteenth and seventeenth hours of the day, workers will perform task actively. Hence, with three shifts per day, work hours of fresh worker when they are supposed to perform actively could be utilized optimally as compared to the two shifts per day. The expected lower output in case of two shifts per day could be altered with the higher output by the addition of a third shift.

**Morale Boosting for All Workers:** Prior to the implementation of this plan, there was an intense lack of hope and comfort in the mind of every worker. They thought that they had not been given credit of any achievement, no matter big or small.

One of the key steps taken to increase the production from this mine was to motivate all workers continually and eliminate hopelessness. The four derives of motivation (acquire, bond, comprehend and defend) can be fulfilled by the primary levers of reward system, culture, job design and performance-management and resource-allocation processes [14].
Workers of this mine had been motivated through following steps:

- Participative management, all workers were realized that they had been directly creating a strong impact on the progress of mine. They were told there had been no difference between an officer and a labor but one’s struggle to show the best. They were also asked to give their suggestion for improvement in every part of the work.
- Team work, workers were always motivated personally as well as in the meeting for showing team work. In every condition, site management made sure the presence of senior management staff in quarry. Workers were realized that as a team member, everyone has to do his own part for the best result.
- Creation of a relax environment, an environment was provided where almost all of his fiscal, social and technical problems had been solved so that he could be able to focus only on his work. The damages to the machinery were least in this month compared to last six months.
- Financial incentives, workers were realized that meeting the assigned production target would mean a bonus and additional rewards to every worker. This step also motivated almost all workers. Observations made during this period inferred that this is the most influencing factor for motivating laborer.

Origination of a New Level: As described previously, there had been only two active levels out of which one had a recovery of less than 5%. It was the need of the hour to originate a new level which could contribute well to meet production targets. A new bench could not be opened in a short time, because of the presence of large compacted pile of waste material in front of the proposed origin point of a new level as shown in figure 4.

A plan had been proposed and executed which would require nearly five months for its completion. A total of approximately (20m ×10m × 10m) 2,000 cbm of waste material needed to be displaced 15 m away from the starting line of a new level. The problem behind this had been lack of required compatible machinery to get the job done. There were three excavators, any one of which could not be independently capable of clearing the area for starting a new level. The company could not bear the expenses to purchase or rent another excavator. In addition, an excavator has also been required for running active levels are (i.e. level zero and level one) simultaneously along with this development. Figure 5 shows the view of area to be cleared in the form of a channel for originating a new level.

The problem was solved by reserving two out of three excavators for the development of area to originate a new level. A team of one experienced and technically sound engineer, a supervisor, four excavator operators and helpers each and four workers (drill men and blast men) for the development works was deputed for completion of this job in the earliest possible time. The teams were distributed into two groups (one for each shift). An engineer, two workers and two excavator operators along with their helpers have been performing duty in the day shift while the remaining workers of the team have been performing duties in the night shift. Work was done for 20 hours per day, 8 hours during regular shift with two hours of overtime work for both shifts.

Fig. 4: Overburden in the new level origination zone.
Fig. 5: Over burden (and waste rock) to be removed to make a channel of 15 m for starting a new level (side view)

While doing work in this schedule, it will take nearly 90 work days for complete clearing of the required area with two excavators, one jack hammer and one small compatible compressor (PDS-185S). After this clearing of the area in the form of a channel, a maiden hole will be drilled on this level with DTH drill machine. Once the holes are drilled, cut and the piece of inclined rock (Figure 4) was removed, the bench will start producing 8 cbm approximately per week of local quality blocks with a DTH, a wire cutter of 50 hp and a spherical with compatible compressor (PDS-185S). Once the slanting piece of rock is completely removed (in expected 20 work days), a gradual increase in production upto 15 cbm per week during the first month and 30 cbm per week during the next two months will be expected.

Hence, not only the declination of production due to complete removal of level one will be overcome but also a rapid increase in the production will be observed after five months of the initiation of this plan.

**CONCLUSION**

Indus Mining (private) limited (IML) has been one of the leading mechanized dimension stone quarrying company of private sector in Pakistan. It has been working on black mamba granite for the last five years. On this deposit of Susal Gali formation, one of the operational mines is AAA mine. The sources of revenue from this mine have been either the regular blocks of different dimension range and quality range as well as the irregular boulder. Flawless block falls into the category of export. With same quality of material, greater the length more will be the revenue of the block. Inspite of fairly good quality of machinery and presence of skilled labor in sufficient quantity, this mine had faced financial crisis. Not only for the progress of this company but also for the growth of dimension stone quarrying and tile cutting sectors, it was necessary to improve monthly production from this mine.

A complete multidimensional set of both short term and medium term plans was proposed for this improvement. A change in quarrying plan with additional focus on proper utilization of worker and machinery was proposed. The deposit contains slating major fractures which lie in both of the two active benches. These fractures cause the bench to drop in more than one piece each of which has weight below or equal to 200 tons. When the thickness of bench was increased by one meter, the weight of pieces had increased by 95 tons approximately which could still be displaced easily. The probability of large blocks also increased in doing so. Hence the revenue generation also increased.

With an optimal reduction in the quantity of machinery utilized, workers (who had been able to operate all machinery other than heavy machinery) were distributed into three shifts of seven hours. This did not only optimize the machinery utilization but also the optimal utilization of work hours was obtained. A shift of seven hours meant a sense of relief to the workers and their proper distribution to the machinery created an increased sense of responsibility. Fresh minded workers exposure time to the machinery was also optimally utilized by doing so. As a part of production improvement plan, workers were motivated through the accomplishment of their fiscal and social needs. Progress based incentives and promotions were introduced into the workers which attracted them to work positively.
A new level origination was also proposed to meet the increased production target. This medium term plan was supposed to be completed within five months. This duration included time for clearing the area through overburden removal, development of bench by cutting slanting rock mass and start of cutting regular bench from this level.

This set of plans when implemented caused a remarkable increase in the production of regular blocks from this mine. Figure 6 shows a pie chart depicting this increase when the plans were implemented during the very start of July 2013.

It is interesting to note that the contributions during and after the month of July and September are maximum which corresponds that the implemented plans did best. Similarly, during the month of August the production is same as during the month of January, however, during this month, site remained closed for eleven days because of holidays on the eve of Eid-ul-Fitr.

REFERENCES